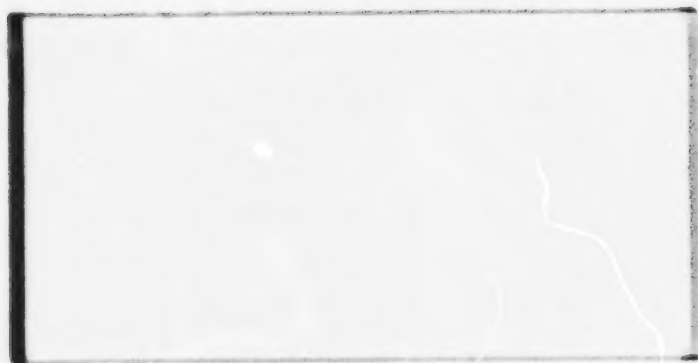


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**RELIABILITY PERFORMANCE OF STANDBY
EQUIPMENT WITH PERIODIC TESTING**

Report No 85-267-K

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ABSTRACT

In this report, the reliability performance of standby equipment subjected to periodic testing is studied. Analytical expressions have been derived for reliability measures, such as the mean accumulated operating time to failure, the expected number of tests between two consecutive failures, the mean time to failure following an emergency start-up and the probability of failing to complete an emergency mission of a specified duration. These results are useful for the reliability assessment of standby equipment such as combustion turbine units of the emergency power supply system, and of the Class III power system at a nuclear generating station.

job	740672-635-022	file	813.07	date	November 29, 1985	report no.	85-267-K
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To Mr. F.J. Kee
Director of Research

RELIABILITY PERFORMANCE OF STANDBY EQUIPMENT
WITH PERIODIC TESTING

1. INTRODUCTION

Standby equipment is usually tested at regular intervals to ensure that it is operable on demand. After the completion of the test, it is returned to the standby status. Examples of such equipment are combustion turbine units in the emergency power supply system, and the Class III power system at a nuclear generating station/1,2,3,4,5/.

In this study, several reliability measures are defined for standby equipment. These include the mean accumulated operating time to failure, the expected number of tests between two consecutive failures, the mean time to failure following an emergency start-up and the probability of failing to complete an emergency mission of a specified duration. General equations are derived for these measures which, in a next step, are simplified by assuming specific distributions for the times to failure in the continuous operation mode.

Specifications for standby equipment are likely to include the starting failure probability and mean time to failure (MTTF) of a similar device in the continuous operation mode. Since such equipment is used in the standby mode, no data on continuous operation can be collected to verify the specified MTTF. It is shown that an estimate of MTTF can be obtained from the knowledge of the mean accumulated operating time to failure in the standby mode, the test duration and the starting failure probability.

2. LIFE CYCLES OF STANDBY EQUIPMENT

The life of a standby equipment is made up of cycles. The life cycles repeat themselves, as shown in Figure 1.

The characteristics of a life cycle are:

- (i) A life cycle starts from the instant when the equipment has completed repair, and is as good as new.

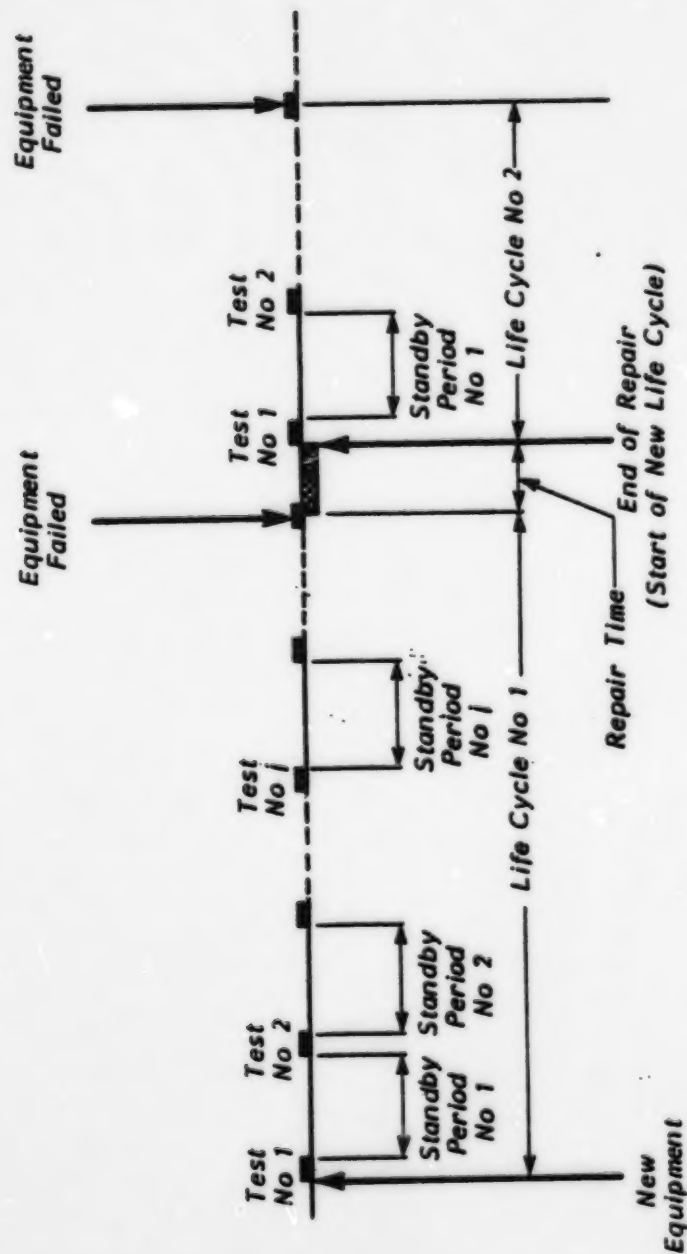


FIGURE 1
LIFE CYCLES OF STANDBY EQUIPMENT

- (ii) Successive tests are made at regular time intervals. During each test, the standby equipment may fail to start.
- (iii) After successful starting, the standby equipment is operated for a period of time during which it may encounter a running failure.
- (iv) On successful completion of the test run, the equipment is returned to standby status.
- (v) A life cycle ends with the detection of either a running or starting failure.

Note that the emergency duty periods are not indicated in Figure 1. They may occur any time between tests; if a failure occurs during a duty period, the life cycle is, of course, terminated. Duty periods are assumed to occur so infrequently (many life cycles are assumed to pass between two consecutive duty periods) that their effect will be neglected.

3. PRELIMINARIES

3.1 Assumptions

- (i) The start-up and shutdown processes of the periodic tests do not change the distribution of the operating times.
- (ii) Starting failures and running failures are independent.
- (iii) The times to operating failure of the equipment may follow an arbitrary distribution.
- (iv) All failures will be detected during the periodic testing.
- (v) Repair restores a failed standby equipment to its "as new" condition. (No assumptions are needed on the repair time distributions for this analysis).
- (vi) Just before test the equipment has the same operating age as it had just after the previous test.
- (vii) The starting failure probability and the test duration are constant.
- (viii) The probability of two or more emergency start-ups in a life cycle is negligible.

3.2 Notations

τ	test duration.
α	starting failure probability of the standby equipment.
$f(t)$	probability density function of times to failure of the equipment in the continuous operation mode.
$F(t)$	probability distribution of times to failure of the equipment in the continuous operation mode.
λ^{-1}	mean time to failure (MTTF) of the equipment in the continuous operation mode, and is therefore the mean of $F(t)$.
v	coefficient of variation of times to failure of the equipment in the continuous operation mode.
L	accumulated operating time to failure of the standby equipment.
X	residual lifetime of the standby equipment following an emergency start-up.
N_s	number of standby periods in a life cycle.
N_t	number of tests initiated in a life cycle.
U	unavailability of the standby equipment due to repairs.
$E(D)$	expected downtime of the standby equipment due to repairs.
I	indicator variable. Note that $I = \begin{cases} 1 & \text{if an emergency occurs} \\ 0 & \text{if no emergency occurs} \end{cases}$
A_j	the emergency event occurs during the j th standby period of the equipment's life cycle.
$P(T I=1)$	probability that the standby equipment will fail to operate successfully for an emergency mission of T hours' duration.
$E(X I=1)$	expected time to failure following an emergency start-up.

4. RELIABILITY MEASURES

In this section, the following reliability measures are derived for an equipment in the standby mode with periodic testing:-

- (i) the mean accumulated operating time to failure,
- (ii) the expected number of tests initiated between two consecutive failures,
- (iii) the expected time to failure for emergency mission, and
- (iv) The probability of failing to complete an emergency mission of a specified duration. (For simplicity, this is called the mission failure probability.)

4.1 Mean Accumulated Operating Time to Failure

The mean accumulated operating time to failure of an equipment in standby mode is determined as follows:

$E(L)$ = mean accumulated operating time until the equipment has either a running failure or starting failure

$$= \sum_{j=1}^{\infty} (1-\alpha)^j \int_{(j-1)\tau}^{j\tau} t \, dF(t) + \sum_{j=2}^{\infty} \alpha (1-\alpha)^{j-1} (j-1)\tau [1-F(j\tau-\tau)] \quad (1)$$

4.2 Expected Number of Tests Initiated Between Two Consecutive Failures

The expected number of tests undergone by an equipment in the standby mode between two consecutive failures is given by

$$E(N_t) = \sum_{j=1}^{\infty} jP(N_t=j) \quad (2)$$

The probability $P(N_t=j)$ that the number of tests initiated in an equipment's life cycle is:

$$P(N_t=1) = \alpha + (1 - \alpha) F(\tau) \quad j=1$$

$$\begin{aligned}
P(N_t=j) &= \text{Prob} \{ \text{first equipment failure occurs during the } j\text{th test} \} \\
&= \text{Prob} \{ \text{equipment survives first } (j-1) \text{ tests and fails the } j\text{th test} \} \\
&= (1-a)^j [F(j\tau) - F(j\tau-\tau)] + a(1-a)^{j-1} [1-F(j\tau-\tau)] \\
&= (1-a)^{j-1} [a + (1-a)F(j\tau) - F(j\tau-\tau)] \quad j = 2, 3, \dots
\end{aligned}$$

Note that

$$\tau[E(N_t) - 1] \leq E(L) \leq \tau E(N_t) \quad (3)$$

This means that the expected number of tests initiated between two consecutive failures can be easily obtained from knowledge of the mean accumulated operating time to failure.

4.3 Expected Time to Failure for Emergency Mission

A useful reliability measure for a standby equipment is the expected time to failure following a successful emergency start-up. This reliability measure is also known as the equipment's residual lifetime. It is derived as follows:

The expected time to failure following a successful emergency start-up is given by:

$$E(X|I=1) = \sum_{j=1}^{\infty} P(A_j|I=1) E(X|A_j, I=1) \quad (4)$$

where $E(X|A_j, I=1)$ and $P(A_j|I=1)$ are obtained as follows:

$E(X|A_j, I=1)$ = expected residual time to failure of a standby equipment following a successful emergency start-up during the j th standby period

$$\begin{aligned}
&= \int_{j\tau}^{\infty} (t-j\tau) dF(t) / [1-F(j\tau)] \\
&= \int_{j\tau}^{\infty} [1-F(t)] dt / [1-F(j\tau)]
\end{aligned}$$

$P(A_j|I=1)$ = probability that the emergency event occurs during the j th standby period of the equipment's life cycle given its occurrence

$$= \sum_{k=j}^{\infty} P(A_j|N_s=k) P(N_s=k)$$

Assume that the emergency event occurs randomly. Since $P(N_s=k) = P(N_t = k+1)$, it can be shown that:

$$\begin{aligned} P(A_j|I=1) &= \sum_{k=j}^{\infty} \frac{1}{k} P(N_t=k+1) \\ &= \sum_{k=j}^{\infty} \frac{1}{k} (1-\alpha)^k [\alpha + (1-\alpha)F(k\tau+\tau) - F(k\tau)] \\ &\quad j=1, 2, 3, \dots \end{aligned}$$

Note that $P(A_j|I=1)$ does not exist for $j = 0$ and

$$\sum_{j=1}^{\infty} P(A_j|I=1) = 1 - P(N_t=1).$$

Normalizing, one obtains

$$\begin{aligned} P(A_j|I=1) &= \sum_{k=j}^{\infty} \frac{(1-\alpha)^k [\alpha + (1-\alpha)F(k\tau+\tau) - F(k\tau)]}{k[1 - P(N_t=1)]} \\ &= \sum_{k=j}^{\infty} \frac{(1-\alpha)^{k-1} [\alpha + (1-\alpha)F(k\tau+\tau) - F(k\tau)]}{k[1 - F(\tau)]} \quad (5) \end{aligned}$$

4.4 Mission Failure Probability

This is the probability that the standby equipment fails to operate successfully for an emergency mission of T hours' duration. It is given by:

$$P(T|I=1) = U + (1-U) \{ \alpha + (1-\alpha) \sum_{j=1}^{\infty} P(T|A_j, I=1) P(A_j|I=1) \}$$

However,

$$P(T|A_j, I=1) = [F(j\tau+T) - F(j\tau)] / [1 - F(j\tau)]$$

and $P(A_j|I=1)$ is given by (5).

Simplifying,

$$P(T|I=1) = U + (1-U) \left\{ \alpha + \sum_{k=1}^{\infty} \sum_{j=1}^k \frac{(1-\alpha)^k Q(k,j)}{k[1-F(\tau)]} \right\} \quad (6)$$

where $Q(k,j) = [F(j\tau+T) - F(j\tau)][\alpha + (1-\alpha)F(k\tau+\tau) - F(k\tau)] / [1 - F(j\tau)]$

The unavailability U of the equipment due to repairs is determined under the assumption that the length of the equipment's life cycle is independent of the equipment's downtime due to repairs. As shown in Figure 1, a life cycle starts immediately following the completion of repair. Hence, the equipment's unavailability is given by:

$$U = \frac{E(D)}{E(L) + E(D)} \quad (7)$$

Note that Equation (6) does not assume that the standby equipment is always as good as new.

Under the assumption that the equipment is always as good as new, the following formula holds:

$$P(T|I=1) = U + (1-U) \{ \alpha + (1-\alpha)F(T) \} \quad (8)$$

Note that Equation (8) is frequently used in practice although a standby equipment after j tests may not be as good as new.

5. SPECIAL CASES

General forms of the reliability measures of the standby equipment with periodic testing have been derived by assuming that the times to running failure of a similar device in the continuous operation mode follow an arbitrary distribution. In this section, the reliability measures are expressed in simpler and computationally convenient forms by specifying the distribution of the times to running failure to be one of the following:-

- (i) Hyperexponential H_2 distribution,
- (ii) Exponential distribution,
- (iii) Erlang E_2 distribution.

5.1 Hyperexponential H_2 Distribution

The probability density function is given by

$$f(t) = \beta \lambda_1 e^{-\lambda_1 t} + (1-\beta) \lambda_2 e^{-\lambda_2 t} \quad t \geq 0$$

where $0 \leq \beta \leq 1$, $\lambda_1 \geq 0$ and $\lambda_2 \geq 0$. The parameters β , λ_1 and λ_2 can be expressed in terms of mean $(1/\lambda)$ and variance (σ^2) of times to running failure as given below:

$$\begin{aligned} \lambda_1 &= 2\lambda, \\ \lambda_2 &= \lambda/(2v^2-1), \text{ and} \\ \beta &= 4(v^2-1)/(4v^2-3) \end{aligned}$$

where v = coefficient of variation
 $= \lambda\sigma$.

The hyperexponential distribution has the following characteristics:

- the coefficient of variation is greater than one;
- it has a decreasing hazard rate function.

Since $F(t)$ is known explicitly, the reliability measures, as given by equations (1), (2), (4) and (6), can be simplified. After performing some algebraic manipulations, the following expressions are obtained for the equipment in the standby mode:

- (i) The mean accumulated operating time to failure is

$$E(L) = \frac{\beta(1-\alpha)(1-e^{-\lambda_1 \tau})}{\lambda_1 [1-(1-\alpha)e^{-\lambda_1 \tau}]} + \frac{(1-\beta)(1-\alpha)(1-e^{-\lambda_2 \tau})}{\lambda_2 [1-(1-\alpha)e^{-\lambda_2 \tau}]} \quad (9)$$

- (ii) The expected number of tests between two consecutive failures is

$$E(N_t) = \frac{\beta}{1-(1-\alpha)e^{-\lambda_1 \tau}} + \frac{1-\beta}{1-(1-\alpha)e^{-\lambda_2 \tau}} \quad (10)$$

(iii) The expected time to failure for continuous operation following an emergency start-up is

$$E(X|I=1) = \sum_{k=1}^M \sum_{j=1}^k \frac{1}{k} (1-\alpha)^{k-1} \left\{ \frac{\beta}{\lambda_1} e^{-j\lambda_1\tau} + \frac{1-\beta}{\lambda_2} e^{-j\lambda_2\tau} \right\} \\ \cdot \{ \beta e^{-k\lambda_1\tau} H(\lambda_1) + (1-\beta) e^{-k\lambda_2\tau} H(\lambda_2) \} / \{ [\beta e^{-\lambda_1\tau} + (1-\beta) e^{-\lambda_2\tau}] [\beta e^{-j\lambda_1\tau} + (1-\beta) e^{-j\lambda_2\tau}] \} \quad (11)$$

where $H(a) = 1 - (1-\alpha)e^{-a\tau}$ and M is the maximum number of tests between two consecutive failures. It approaches infinity theoretically. However, in practice, the value of M is finite. From computational experience, it is good enough to set $M = 200$ for $\lambda^{-1} \leq 1000$ hr.

(iv) The failure probability of an emergency mission is given by

$$P(T|I=1) = U + (1-U) \left\{ \alpha + \sum_{k=1}^M \sum_{j=1}^k \frac{(1-\alpha)^k Q(k,j)}{k [\beta e^{-\lambda_1\tau} + (1-\beta) e^{-\lambda_2\tau}]} \right\} \quad (12)$$

$$\text{where } Q(k,j) = \left[1 - \frac{\beta e^{-\lambda_1(j\tau+T)} + (1-\beta) e^{-\lambda_2(j\tau+T)}}{\beta e^{-\lambda_1 j\tau} + (1-\beta) e^{-\lambda_2 j\tau}} \right] [\beta e^{-k\lambda_1\tau} H(\lambda_1) + (1-\beta) e^{-k\lambda_2\tau} H(\lambda_2)]$$

5.2 Exponential Distribution

The probability density function is given by

$$f(t) = \lambda e^{-\lambda t} \quad t \geq 0$$

where $MTTF = 1/\lambda$ and $v = 1$.

The hazard rate function for the exponential distribution is constant. The following results are obtained:

$$(i) \quad E(L) = (1-\alpha)(1-e^{-\lambda\tau}) / [\lambda\{1-(1-\alpha)e^{-\lambda\tau}\}] \quad (13)$$

$$(ii) \quad E(N_t) = \beta / [1-(1-\alpha)e^{-\lambda\tau}] \quad (14)$$

$$(iii) \quad E(X|I=1) = 1/\lambda \quad (15)$$

$$(iv) \quad P(T|I=1) = U + (1-U)[\alpha + (1-\alpha)(1-e^{-\lambda T})] \quad (16)$$

The above results (iii) and (iv) show that an equipment with exponential distributed times to failure is always as good as new.

5.3 Erlang E_2 Distribution

The probability density function is given by

$$f(t) = 2\lambda(2\lambda t)e^{-2\lambda t} \quad t \geq 0$$

where the mean and coefficient of variation are $1/\lambda$ and $1/\sqrt{2}$ respectively,

The Erlang E_2 distribution has an increasing hazard rate function. The following results are obtained:

$$(i) \quad E(L) = \frac{(2-\alpha)\tau\omega}{(1-\omega)^2} + \frac{2\lambda\tau^2\omega(1+\omega)}{(1-\omega)^2} + \frac{(1-\alpha)}{\lambda} \left[\frac{1}{1-\omega} - \left\{ \frac{1}{1-\omega} + \frac{2\lambda\tau}{(1-\omega)^2} + \frac{2\lambda^2\tau^2(1+\omega)}{(1-\omega)^3} \right\} e^{-2\lambda\tau} \right] \quad (17)$$

where $\omega = (1-\alpha)e^{-2\lambda\tau}$.

$$(ii) \quad E(N_t) = \frac{1}{(1-\omega)^2} + \frac{4\lambda\tau\omega}{(1-\omega)^3} - (1-\alpha) \left[\frac{1}{(1-\omega)^2} + \frac{2\lambda\tau(1+\omega)}{(1-\omega)^3} \right] e^{-2\lambda\tau} \quad (18)$$

$$(iii) \quad E(X|I=1) = \sum_{k=1}^M \sum_{j=1}^k (1-\alpha)^{k-1} (1+\lambda j\tau) e^{-2\lambda(k-1)\tau} [1+2\lambda k\tau - (1-\alpha) \cdot \{1 + 2\lambda(k+1)\tau\} e^{-2\lambda\tau}] / [k\lambda(1+2\lambda j\tau)(1+2\lambda\tau)] \quad (19)$$

$$(iv) P(T|I=1) = U + (1-U) \left\{ \alpha + \sum_{k=1}^M \sum_{j=1}^k \frac{(1-\alpha)^k Q(k,j)}{k(1+2\lambda\tau) e^{-2\lambda\tau}} \right\} \quad (20)$$

$$\text{where } Q(k,j) = e^{-2\lambda k\tau} [1+2\lambda k\tau - (1-\alpha) \{1+2\lambda(k+1)\tau\} e^{-2\lambda\tau}] \\ \cdot [1 - \frac{1+2\lambda(j\tau+T)}{1+2\lambda j\tau} e^{-2\lambda T}]$$

6. NUMERICAL RESULTS

Consider a standby combustion turbine unit with operating and maintenance characteristics as described in this report.

6.1 Mean Accumulated Operating Time to Failure

The mean accumulated operating time to failure of the equipment in standby mode is computed for specified values of λ^{-1} , τ , α and v . The results are shown in Figures 2 to 6.

As expected, Figure 2 shows that the mean accumulated operating time to failure decreases significantly with increasing values of starting failure probability.

Figure 3 shows that the mean accumulated operating time to failure increases significantly with increasing values of test duration.

Figures 4, 5 and 6 show that the mean accumulated operating time to failure increases with increasing values of the mean time to failure of the same equipment in continuous operation mode. The rate of increase of $E(L)$ decreases with increasing λ^{-1} . This means that as λ^{-1} becomes large (eg, $\lambda^{-1} > 800$ h), the starting failure becomes a dominant failure cause.

6.2 Estimation of MTTF (λ^{-1})

In practice, the following information can be extracted from recorded data of the equipment in standby mode:

- (i) mean accumulated operating time to failure
- (ii) starting failure probability,
- (iii) average test duration.

The mean time to failure for such an equipment in the continuous operation mode can be easily estimated from Figure 6. As an example, let

$$\begin{aligned}\alpha &= 0.04, \\ \tau &= 1.5 \text{ h, and} \\ E(L) &= 27.5 \text{ h}\end{aligned}$$

The following results are obtained:

$$\lambda^{-1} = \begin{cases} 90 \text{ h for } v = 0.71 & (\text{Erlang } E_2 \text{ distribution}) \\ 120 \text{ h for } v = 1.00 & (\text{Exponential distribution}) \\ 175 \text{ h for } v = 1.25 & (\text{Hyperexponential } H_2 \text{ distribution}) \\ 220 \text{ h for } v = 2.00 & (\text{Hyperexponential } H_2 \text{ distribution}) \end{cases}$$

Note that the coefficient of variation of times to failure affects the estimated value of λ^{-1} significantly.

6.3 Expected Time to Failure for Emergency Mission

The mean time $E(X|I=1)$ to failure of the standby equipment following an emergency start-up is computed for specified values of λ^{-1} , α , τ , and v . The results are tabulated in Table 1. As expected, an equipment with exponential times to failure is not affected by the periodic test policy and is as good as new. For an equipment with increasing (decreasing) hazard rate function, $E(X|I=1)$ is less (greater) than λ^{-1} .

TABLE 1 :

Expected Time to Failure of Standby Equipment
Following an Emergency Start-Up

($\alpha = 0.04$ and $\tau = 1.5 \text{ hr}$)

Mean time to failure of new equipment, λ^{-1} (hours)	Expected time to failure for emergency mission, $E(X I = 1)$ (hours)		
	$v = 1.25$ (Hyperexponential)	$v = 1.0$ (Exponential)	$v = 1/\sqrt{2}$ (Erlang E_2)
100	107.5	100	89.9
200	208.7	200	186.7
300	309.1	300	285.1
400	409.4	400	384.2
500	509.5	500	483.5
600	609.6	600	583.1
700	709.7	700	682.7
800	809.7	800	782.4

6.4 Mission Failure Probability

The failure probability of an emergency mission is computed for specified values of λ^{-1} , α , τ , v and U . The results are tabulated in Table 2.

For a standby equipment with Erlang times to failure, the reliability performance is better for new equipment compared with that of the old equipment. The opposite is true for a standby equipment with hyperexponential times to failure. However, the performance of an equipment with exponential times to failure does not depend on its age (as shown in Section 4.2).

TABLE 2

Probability of Equipment Failing to Complete
a 36-Hour Emergency Mission

($\alpha = 0.04$, $\tau = 1.5$ hr, and $U = 0.06$)

Mean time to failure of new equipment, λ^{-1} (hours)	Mission failure probability $P(T I = 1)$			
	$v = 1.25$		$v = 1/\sqrt{2}$	
	Standby	New	Standby	New
100	0.4466	0.4615	0.3087	0.2445
200	0.3037	0.3090	0.1739	0.1438
300	0.2435	0.2461	0.1366	0.1198
400	0.2104	0.2120	0.1213	0.1106
500	0.1896	0.1906	0.1135	0.1061
600	0.1752	0.1760	0.1090	0.1036
700	0.1647	0.1653	0.1062	0.1021
800	0.1567	0.1572	0.1043	0.1010

7. CONCLUSIONS

The reliability performance of standby equipment with periodic testing has been studied. Analytical expressions have been derived for several measures describing that performance.

The mean accumulated operating time to failure of the standby equipment is found to be dependent on the test duration, the starting failure probability, and the mean and variance of the times to failure of an identical device in the continuous operation mode. It is considerably less than the mean time to failure ($1/\lambda$) of an identical device in the continuous operation mode. This is primarily due to starting failures.

Bounds of the mean accumulated operating time to failure of standby equipment can be obtained from the knowledge of the expected number of tests between two consecutive failures.

The expected time to failure ($E(X|I=1)$) and the mission failure probability $P(T|I=1)$ of the standby equipment following an emergency start-up are found to be greatly dependent on the probability distribution $F(t)$ of the times to failure of an identical device in continuous operation mode. The following conclusions can be drawn:-

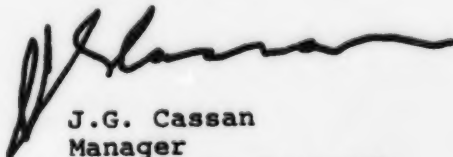
(a) $E(X|I=1) > 1/\lambda$ for equipment with decreasing hazard rate function,

$E(X|I=1) = 1/\lambda$ for equipment with constant hazard rate function, and

$E(X|I=1) < 1/\lambda$ for equipment with increasing hazard rate function.

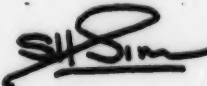
(b) The mission failure probability of a standby equipment is lower than that of a new equipment for decreasing hazard rate function. The opposite is true for increasing hazard rate function. Such differences diminish as the mean time to failure ($1/\lambda$) becomes larger.

Approved:



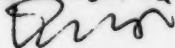
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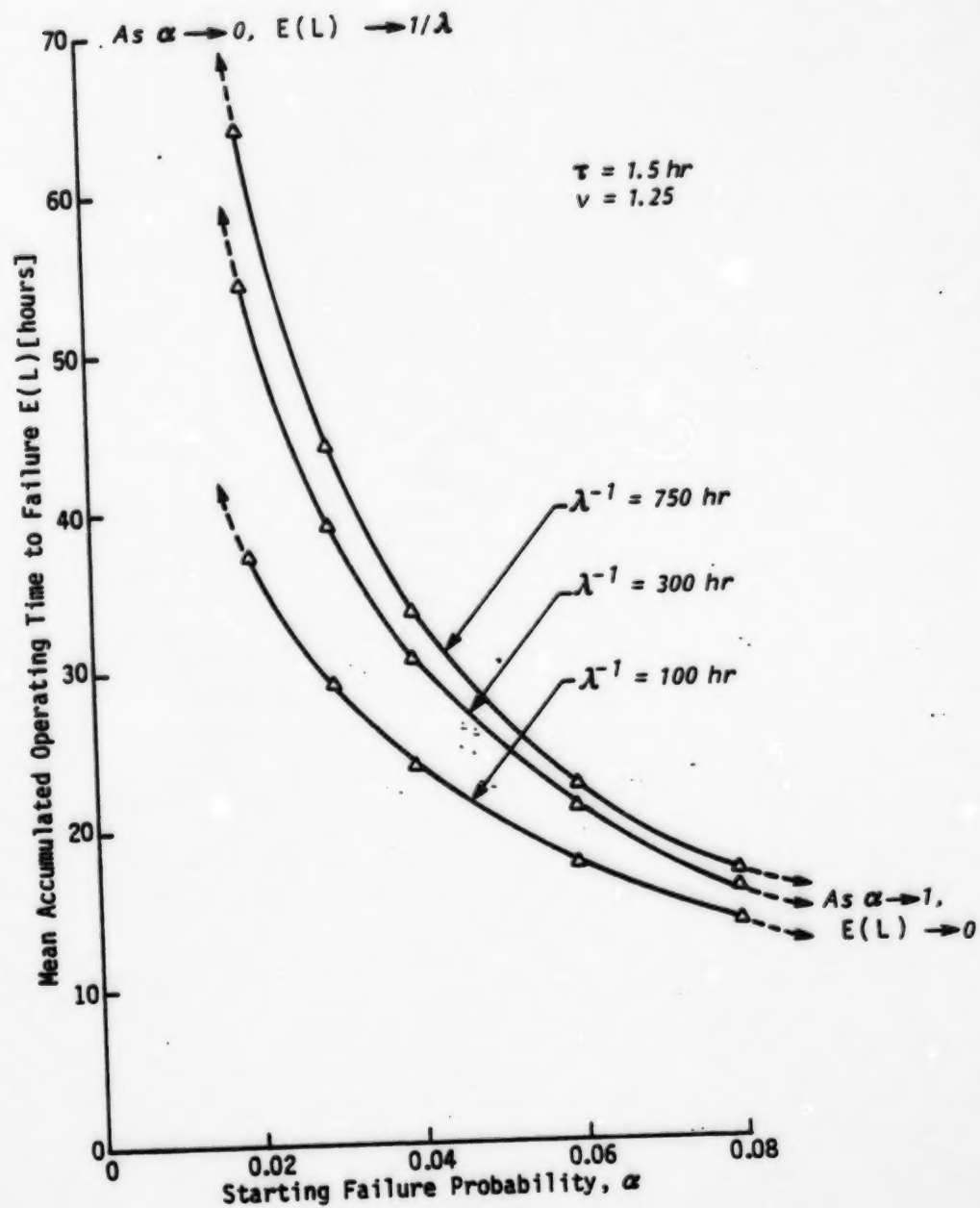


FIGURE 2
THE EFFECT OF STARTING FAILURE PROBABILITY
ON MEAN ACCUMULATED OPERATING TIME TO FAILURE

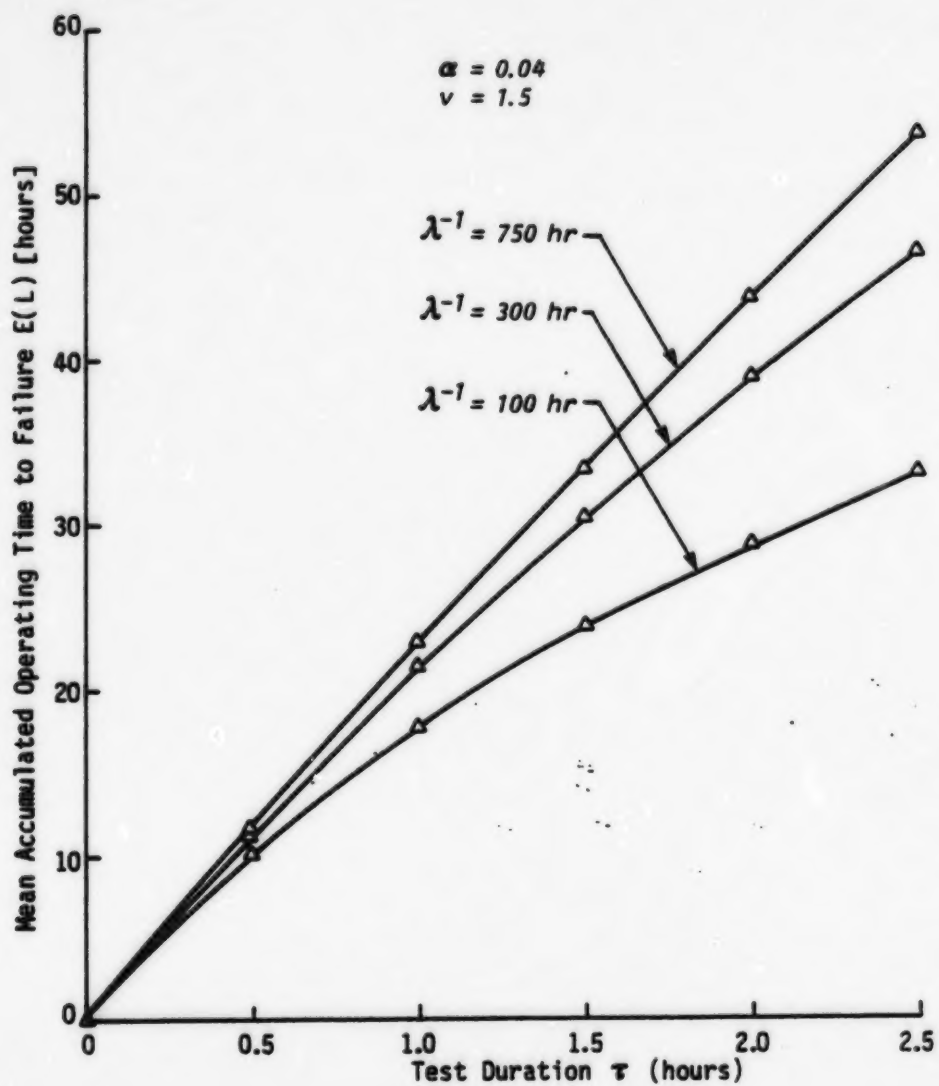


FIGURE 3
 THE EFFECT OF TEST DURATION ON MEAN
 ACCUMULATED OPERATING TIME TO FAILURE

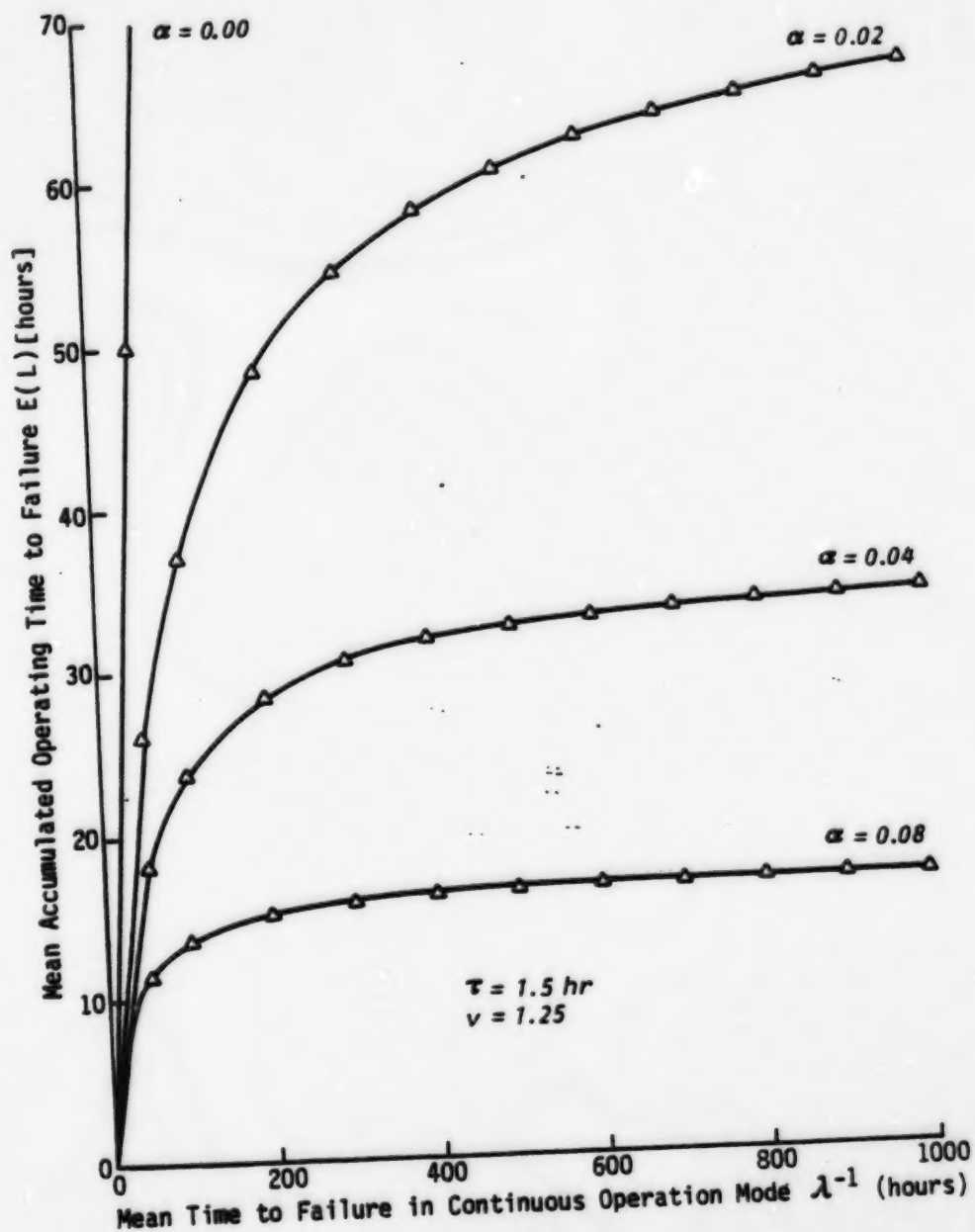


FIGURE 4
THE EFFECT OF MEAN TIME TO FAILURE (CONTINUOUS
OPERATION) ON MEAN ACCUMULATED OPERATING TIME
TO FAILURE (STANDBY OPERATION)

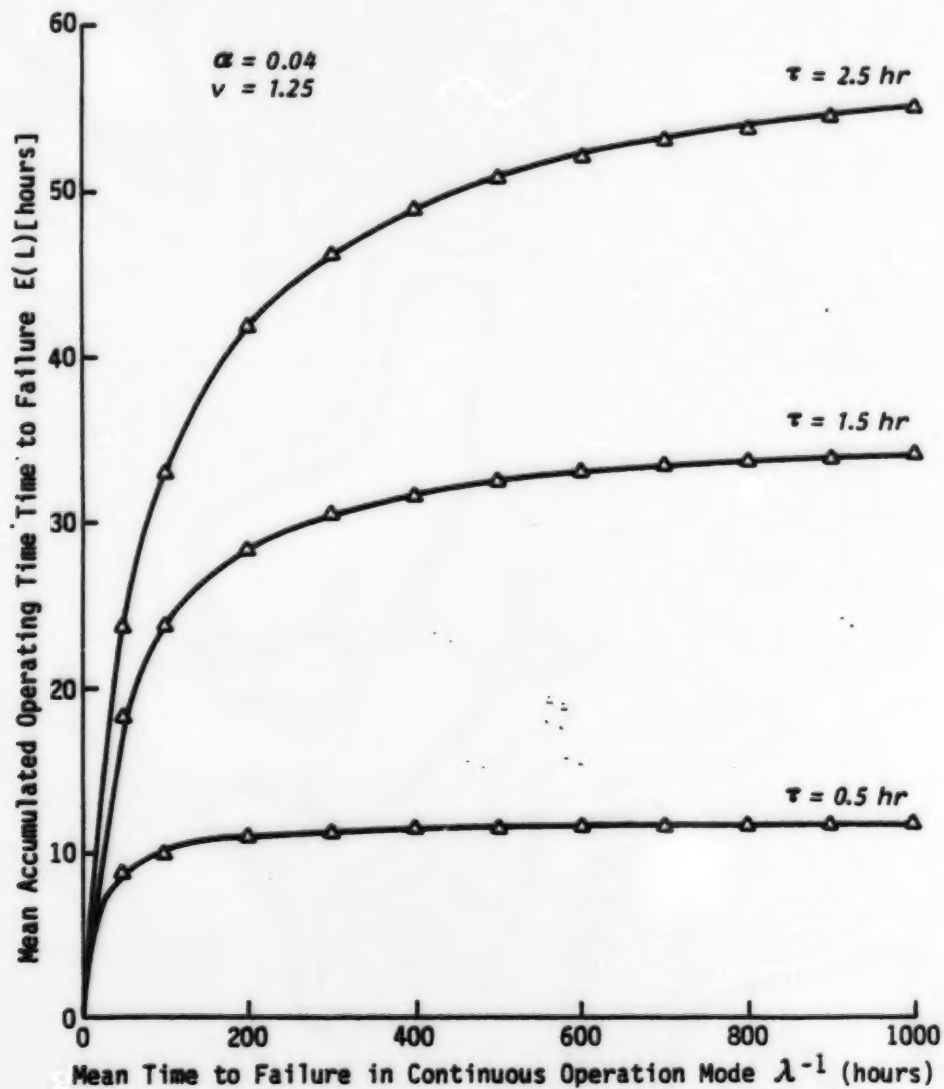


FIGURE 5
THE EFFECT OF MEAN TIME TO FAILURE (CONTINUOUS OPERATION) ON MEAN ACCUMULATED OPERATING TIME TO FAILURE (STANDBY OPERATION)

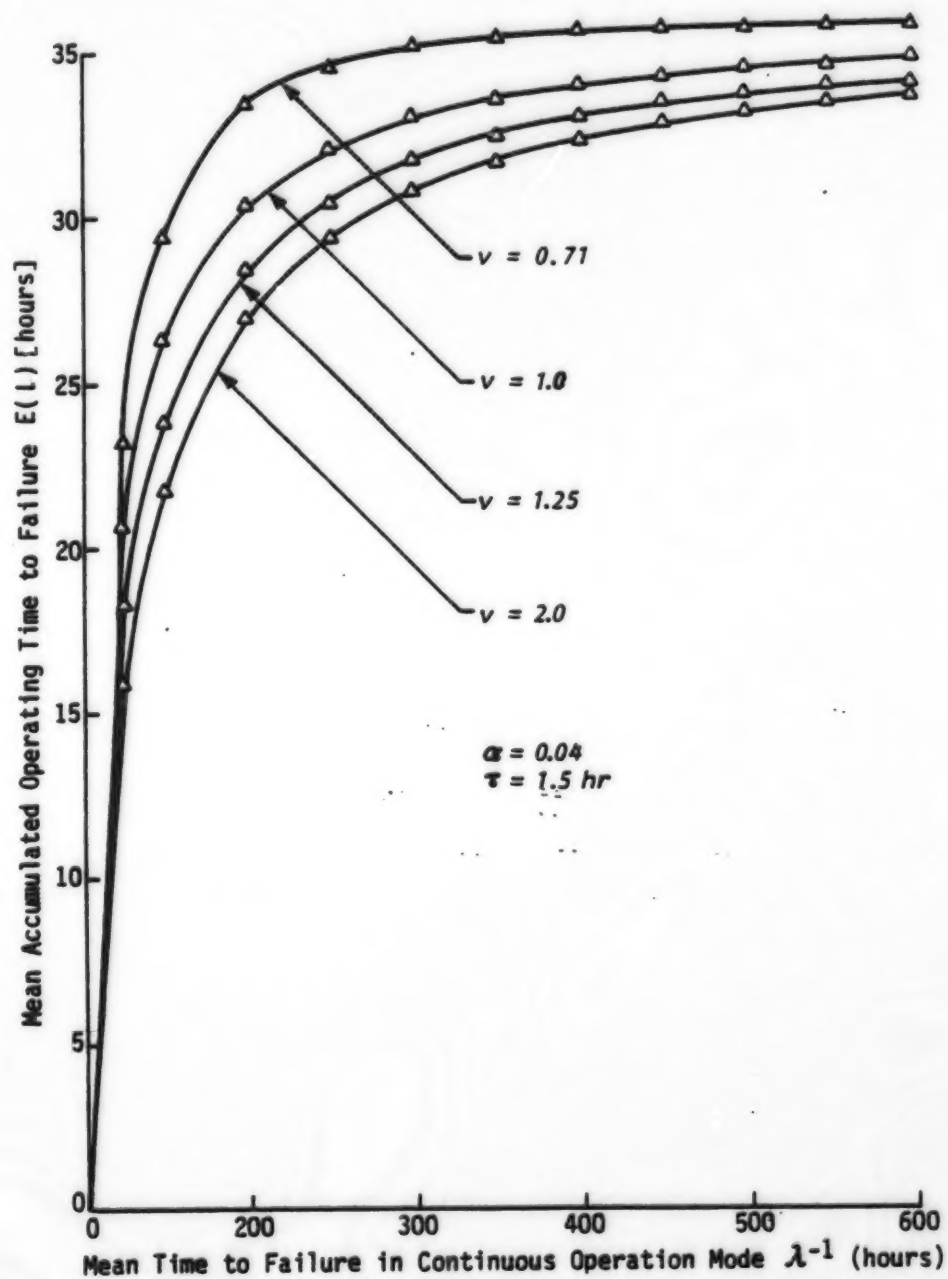


FIGURE 6
THE EFFECT OF MEAN TIME TO FAILURE (CONTINUOUS
OPERATION) ON MEAN ACCUMULATED OPERATING TIME
TO FAILURE (STANDBY OPERATION)